

Steering System for Vehicles

This invention relates to a steering system for automotive vehicles, and more particularly to a steering system adapted for use with vehicles having at least two steerable wheel units.

Background of the Invention

In the automotive industry, there has been developed certain types of vehicles equipped with multiple steerable wheel units. Such vehicles have included vehicles with 4x4, 6x6, 8x8 and 10x10 wheel configurations. Typically, each of such vehicles has been equipped with a steering system peculiar to the particular wheel configuration of the vehicle. In this regard, it has been found to be desirable to provide a single steering system which can be easily modified to accommodate any of such vehicle configurations.

Accordingly, it is the principal object of the present invention to provide a novel steering system which can be modified to accommodate 4x4, 6x6, 8x8 and 10x10 wheel configurations. Further objects of the invention are to provide such a system in which the various modifications thereof provide a commonality of components, highly responsive steering wheel operation, left or right hand drive and concentric wheel tracks when the wheels are turned.

Summary of the Invention

The aforementioned objects are achieved by providing a steering system for a vehicle having a body supported on at least two sets of steerable wheels, generally consisting of a steering shaft provided with a wheel supported on the vehicle body, a torque transmitting main shaft supported longitudinally on the vehicle body, means operatively interconnecting the steering shaft and the main shaft for transmitting rotary motion of the steering shaft to rotary motion of the main shaft, first transversely displaceable means operatively interconnecting knuckle brackets of one of the sets of steerable wheels, means operatively interconnecting the main shaft and the first transversely displaceable means for translating rotary motion of the main shaft to linear motion of the first transversely displaceable means, second transversely displaceable means operatively interconnecting knuckle brackets of the other set of steerable wheels, and means operatively interconnecting the main shaft and the second transversely displaceable means for translating rotary motion of the main shaft to linear motion of the second transversely displaceable means. With such two sets of wheels, a 4x4 vehicle configuration is

provided. Such 4x4 vehicle configuration can be modified to a 6x6 configuration simply by adding a nonsteerable wheel unit between such steerable wheel units, modified to an 8x8 vehicle configuration by adding a slaved, steerable wheel to each of such two sets of steerable wheel units and modified to a 10x10 vehicle configuration by adding a slaved, steering wheel unit to each of such sets of steerable wheel units and adding a nonsteerable wheel unit between the slaved, steerable wheel units. In each of such configurations, the steerable wheel units are essentially of the same construction utilizing common components, and the nonsteerable wheel units are similar in construction and are provided with components common to all wheel units.

The steering shaft assembly of the system is adapted to be displaced transversely to provide left hand or right hand drive of the vehicle. The steering wheel along with the operator's seat is displaceable substantially vertically.

Precision steering response is provided by ball and socket connections of the various components of the system. Furthermore, concentric wheel tracks during turning of the vehicle is provided by arranging for the axes of the steerable wheels of the vehicle intersecting at a point on a line perpendicular to the longitudinal centerline of the vehicle at a midpoint of the vehicle.

The steering system described herein particularly is suitable for use in vehicles equipped with wheel suspension systems of the type described in that certain pending PCT Patent Application entitled Wheel Unit for Automotive Vehicles, filed on the same date hereof, which is incorporated herein by reference.

Brief Descriptions of the Drawings

Figure 1 is a perspective view of a vehicle having a 10x10 wheel configuration, embodying the present invention;

Figure 2 is a perspective view of the vehicle shown in Figure 1 illustrating the steering system of the vehicle embodying the present invention, in solid lines, and the other vehicle components in phantom lines;

Figure 3 is an enlarged, perspective view of the steering system shown in Figure 2;

Figure 4 is an enlarged, perspective view of the steering column of the system shown in Figures 2 and 3;

Figure 5 is an enlarged, perspective view of the first and second steering assemblies shown in Figures 2 and 3, operable to steer the first and second sets of wheels of the vehicle;

Figure 6 is an enlarged, perspective view of the fourth and fifth steering assemblies shown in Figures 2 and 3, operable to steering the fourth and fifth sets of wheels of the vehicle;

Figure 7 is an enlarged, perspective view of the mechanism provided in the assemblies shown in Figures 5 and 6 for translating rotary motion to linear motion for steering the wheels of associated sets of wheels;

Figure 8 is a front view of the mechanism shown in Figure 7;

Figure 9 is a side, elevational view of the mechanism shown in Figure 8;

Figure 10 is a cross-sectional view taken along 10-10 in Figure 9;

Figure 11 is a top plan view of the mechanism shown in Figure 7;

Figure 12 is an enlarged, cross-sectional view taken along line 12-12 in Figure 8;

Figure 13 is a perspective view of a modification of the system shown in Figure 3, suitable for use in a vehicle having a 6x6 wheel configuration;

Figure 14 is an enlarged, perspective view of the first steering assembly shown in Figure 13, operable to steer a first set of wheels;

Figure 15 is an enlarged, perspective view of the second steering assembly of the system shown in Figure 13, operable to steer a third set of wheels;

Figure 16a is a diagram of the steerable wheels of a vehicle having a 4x4 wheel configuration, traveling in a straight ahead mode, not providing a full Ackerman effect;

Figure 16b is a diagram of the steerable wheels shown in Figure 16a, traveling in a turning mode;

Figure 16c is a diagram of the steerable wheels of a vehicle embodying the present invention, comparable to the steering wheel arrangement shown in Figure 16a, traveling in a straight ahead mode, providing a full Ackerman effect;

Figure 16d is a diagram of the steerable wheels shown in Figure 16c, traveling in a turning mode;

Figure 17a is a diagram of the steering wheels of a vehicle having an 8x8 wheel configuration, traveling in a straight ahead mode, not providing a full Ackerman effect;

Figure 17b is a diagram of the steerable wheels of the vehicle shown in Figure 17a, traveling in a turning mode;

Figure 17c is a diagram of the steerable wheels of a vehicle embodying the present invention, comparable to the steering wheel arrangement shown in Figure 17a, traveling in a straight ahead mode, providing a full Ackerman effect;

Figure 17d is a diagram of the steerable wheels shown in Figure 17c, traveling in a turning mode;

Figure 18a is a diagram of the steerable and single nonsteerable wheels of a prior art vehicle having a 10x10 wheel configuration, traveling in a straight ahead mode;

Figure 18b is a diagram of the steerable and nonsteerable wheels shown in Figure 18a traveling in a turning mode;

Figure 19 is a perspective view of an operator's station of the vehicle shown in Figures 1 and 2, including a steering assembly and operator's seat in the left hand drive position;

Figure 20 is a perspective view similar to the view shown in Figure 19, illustrating the steering assembly in a right hand drive position;

Figure 21 is a side elevational view of the steering column assembly and operator's seat shown in Figures 19 and 20, in a lower position; and

Figure 22 is a view similar to the view shown in Figure 21, illustrating the steering assembly and operator's seat in an elevated position.

Detailed Description of the Embodiments of the Invention

Referring to Figures 1 and 2 of the drawings, there is illustrated an automotive vehicle 20 generally consisting of a monocoque body or hull 21 mounted on a set of wheel units 22, a power plant mounted within the body, a drive train for transmitting drive from the power plant to the wheel units, a steering system 23 mounted on the body and operatively connected to the steerable wheel units and various other auxiliary equipment and systems. Steering system 23 generally includes a motion transmitting assembly 24, a steering column assembly 25, wheel steering assemblies 26 through 29 and a nonsteerable assembly 30. Motion transmitting assembly 24 essentially functions to transmit rotary motion from steering column assembly 25 to steerable assemblies 26 through 29. Steering column assembly 25 is located at the operator's station on the vehicle and functions in the conventional manner to transmit rotary motion of the manually operated steering wheel to motion transmitting assembly 24 to turn the steerable assemblies. Wheel steerable assembly 26 interconnects a first set of wheels and is operatively

connected to the motion transmitting assembly for translating the rotary motion of assembly 24 to linear motion of assembly 26. Steerable assembly 27 interconnects a second set of wheels of the vehicle and is slaved to assembly 26 for displacing transversely responsive to motion imparted by its master assembly 26. Steerable assembly 29 is similar to master assembly 26 but angularly displaced 180° relative to assembly 26, about a vertical axis. Such assembly interconnects a fifth set of wheels and similarly is operatively connected to assembly 24 for translating rotary motion of assembly 24 to transversely disposed linear motion of assembly 29. Steerable assembly 28 is similar to steering assembly 27 and is slaved to master assembly 29. It also is displaceable transversely by motion imparted by master assembly 29 and operatively interconnects a fourth set of wheels. Nonsteerable assembly 30 is disposed at the center of the vehicle and interconnects a set of nonsteerable wheels. Each of assemblies 26 through 30 is connected to a set of knuckle brackets of wheel units of the type as described and illustrated in aforementioned PCT Patent Application entitled Wheel Unit for Automotive Vehicles.

As best shown in Figure 3, motion transmitting assembly 24 includes a transversely disposed shaft 31 located at the lower, front end of the vehicle adjacent the operator's station, a longitudinally disposed main shaft 32 and a short shaft 33 operatively interconnecting transversely disposed shaft 31 and longitudinally disposed shaft 32. Shaft 31 is rotatable about its axis and is connected at one end to a gear box 34 which functions to transmit the rotary motion of shaft 31 to rotary motion of shaft 33. Short shaft 33 is connected to main shaft 32 through a universal connection 35 which functions to transmit rotary motion of short shaft 33 to rotary motion of main shaft 32. Steering column assembly 25 generally includes a column 36, a steering shaft 37 journaled in column 36 and a conventional steering wheel 38 provided on the upper end of the steering shaft, accessible to the vehicle operator. Rotary motion of steering shaft 37 is transmitted to transversely disposed shaft 31 by means of a gear box 39. Shaft 37 has a slot and key type of connection with a gear of gear box 39 to permit the steering shaft assembly to be displaced along the axis of shaft 37, and transversely disposed shaft 31 similarly has a slot and key type of connection with a gear of gear box 39 so that the steering shaft assembly may be moved transversely along shaft 31.

As best shown in Figures 5 through 10, master steerable assembly 26 includes a transversely displaceable, connecting plate 40, a pair of tie rods 41 and 42, a steering gear unit 43

and a linkage 44 operative to translate rotary motion of the steering gear unit to linear motion of plate 40. Connecting plate 40 includes a horizontal plate portion 40a and a vertical plate portion 40b which is guided transversely by a housing 45 mounted on a transversely disposed plate portion of the vehicle body. Tie rod 41 operatively interconnects a protruding portion of plate 40 with a knuckle bracket 46 of a wheel unit by means of ball and socket connections. Similarly, tie rod 42 operatively interconnects a protruding portion of plate 40 with a knuckle bracket 47 of a wheel unit by means of a similar set of ball and socket connections. Steering gear unit 43 is of a conventional construction and functions in a conventional manner to enhance torque transmitted to steerable assembly 26. At an upper end thereof, it is operatively connected to main shaft 32 by means of a connection 48 and is provided at a lower end thereof with a longitudinally disposed output shaft 49.

Linkage 44 includes a Pittman arm 50 mounted on output shaft 49 and extending radially thereof and a link 51 consisting of a pair of spaced plates 51a and 51b pivotally connected at one set of ends to the free end of Pittman arm 50 and pivotally connected at an opposite set of ends to an upwardly projecting portion 40c of plate 40. To eliminate any lash in linkage 44 which would be detrimental to the responsiveness of the steering system, the connections of side plates 51a and 51b of link 50 with Pittman arm 50 and upwardly projecting portion 40c are provided with ball and socket connections as best shown in Figure 12.

Referring to Figure 12, side plates 51a and 51b of link 51 are spaced apart by a spacer 60 and secured together by means of a set of bolts 61 and 62 extending through openings in side plate 51a and spacer 60 and threaded into threaded openings in side plate 51b. The free end of Pittman arm 50 is received between one set of ends of side plates 51a and 51b and is provided with an opening 63 therethrough having an enlarged section 64 providing an annular seating surface 65. Disposed in the enlarged section and seated on annular surface 65 is a first bearing seat element 66 having a spherical bearing surface 67. A spherical bearing 68 is seated on bearing surface 67, which is provided with a tapered opening 69 therethrough. A second bearing seat element 70 is disposed in enlarged section 64, having a spherical bearing surface 71 engaging bearing 68 and secured in position by a threaded nut 72 threaded into a threaded end portion of enlarged section 64. A tapered pin 73 is inserted through an opening 74 in side plate 51a registrable with tapered opening 69 in bearing 68, and is threaded into a threaded opening provided in side plate 51b. The head of pin 73 is formed with a nut portion 75 to permit a

wrench to be applied thereon in inserting the pin in the registered openings to pivotally connect the Pittman arm to link 51. To preclude the entry of foreign matter between bearing surfaces, O-rings 76 and 78 are provided between the sides of the Pittman arm and the side plates of link 51.

The connection of the other end of side plates 51a and 51b to upwardly projecting portion 40c of plate 40 is similar to the connection of such plates to the Pittman arm. With such snug fits of the pivot pins with the spherical bearings, and the spherical interfaces of the bearings with their respective bearing seats, little if any lash will occur in translating the rotary motion of output shaft 49 of the steering gear unit to the linear motion of plate 40.

Slaved steerable assembly 27, as shown in Figure 5, generally includes a pair of tie rods 80 and 81 comparable to tie rods 41 and 42 of master steerable assembly 26, and a motion translating mechanism 82, as best shown in Figures 9 through 11. The mechanism consists of a longitudinally disposed, tubular housing 83 supported on transversely disposed plate members of the vehicle body, and extending below master steerable assembly 26, and a set of longitudinally disposed, transversely spaced pins 84 and 85 also mounted on a transversely disposed plate member of the vehicle body. Mounted in tubular housing 83 is a transfer shaft 86 rotatable about its axis which is disposed parallel to the axes of pins 84 and 85. The forward end of shaft 86 is provided with a radially disposed arm member 87 which extends upwardly between the transversely spaced, forwardly protruding portions of plate 40. As best seen in Figure 7, the upper end of arm member 87 is provided with a longitudinally disposed pin 88 which is pivotally connected to a link 89. The opposite end of link 89 is pivotally connected to a substantially vertical pin 90 on plate member 40 so that upon transverse linear displacement of plate member 40, such motion will be translated to pivotal motion of shaft 86 about its axis.

Pivotally mounted on pins 84 and 85 are a pair of crank arms 91 and 92. Tie rod 80 is pivotally connected at an inner end thereof to the upper end of arm member 91 by means of a connecting pin 93 and the outer end thereof is pivotally connected to a knuckle bracket 94 of a wheel of the second wheel assembly. Similarly, tie rod 81 is pivotally connected at an inner end thereof to the upper end of arm member 92 by means of a connecting pin 94a and is pivotally connected at an outer end thereof to a knuckle bracket 95 of a wheel of the second wheel assembly. The lower ends of arm members 91 and 92 are connected to a radially disposed portion 96 of shaft 86 by means of links 97 and 98 pivotally connected at their inner ends to radial disposed portion 96 by means of pivot pin 99 and pivotally connected at their outer ends to

the lower ends of arm members 91 and 92 by means of connecting pins 100 and 101, respectively.

With the connection of slaved steerable assembly 27 to master steerable assembly 26 as described, it will be appreciated that the transverse, linear motion of plate member 40 of assembly 26 will be transmitted through mechanism 82 to tie rods 80 and 81 to cause the second wheel assembly to turn in unison with the first wheel assembly.

Master steerable assembly 29 is substantially similar in construction and operation to master steerable assembly 26 and is reoriented 180° about a vertical axis to provide for the associated wheels thereof to turn in a direction opposite the direction of the wheels associated with steerable assembly 26, and thus allow the vehicle to turn in the conventional manner. Steerable assembly 28 is slaved to master cylinder assembly 29 and also is reoriented 180° relative to and is similar in construction and operation to slaved steerable assembly 27. Because of the reorientation of steerable assemblies 28 and 29, drive from main drive transmitting shaft 32 must be transferred to the other side of the vehicle which is achieved through a chain drive assembly 110. Such assembly consists of a shaft 111 journaled in a bearing block mounted on a transverse plate member of the vehicle body, having a set of sprockets mounted thereon and being operatively connected to steering gear unit 112 of assembly 29 by means of a universal connection 113, a pair of sprockets mounted on the rear end of main shaft 32, a number of idler sprockets 114 rotatably mounted on shafts connected to transverse plate members of the vehicle body, and a set of chains 115 trained about the drive sprockets mounted on the end of shaft 32, driven sprockets mounted on shaft 111 and idler sprockets 114.

Nonsteerable assembly 30 consists merely of a connecting plate member 120 supported on the vehicle body, a pair of tie rods 121 and 122 connected at their inner ends to plate member 120 and connected at their outer ends to knuckle brackets 123 and 124 of the wheels of the third wheel assembly.

With the arrangement as shown in Figure 3, whenever steering wheel 38 is turned, such rotary motion will be transmitted through assembly 25 to master steerable assemblies 26 and 29 and through such assemblies to slaved steerable assemblies 27 and 28 to cause the vehicle to turn either to the right or left.

The system shown in Figure 3 may easily be modified to an 8x8 configuration by omitting nonsteerable assembly 30 and adjusting the wheel base, a 6x6 configuration by omitting

slaved steerable assemblies 27 and 28, retaining non-steerable assembly 30 a and adjusting the wheel base, as shown in Figure 13, and a 4x4 configuration by eliminating slaved steerable assemblies 27 and 28 and nonsteerable assembly 30 and adjusting the wheel base. It further will be appreciated that such steerable and nonsteerable assemblies in all of such configurations utilize a maximum number of common components.

Figure 14 illustrates a steerable assembly without an operatively connected slaved steerable assembly, which may be used in 4x4 and 6x6 wheel configurations. Such assembly is essentially identical to steerable assembly 27 utilized in the 10x10 and 8x8 wheel configurations. Figure 15 illustrates a steerable assembly without an operatively connected slaved steerable assembly which also is adapted for use in 4x4 and 6x6 wheel configurations. It is similar in construction and operation to master steerable assembly 29 described in connection with the steering arrangement for a 10x10 wheel configuration.

It is contemplated that the steering column assembly 25 described in connection with the embodiment shown in Figure 3 will be employed in a steering wheel assembly 130 in association with an operator's seating assembly 131 as shown in Figures 19 through 22. Steering wheel assembly 130 includes a support frame 132 having a lower frame section 133 and upper frame section 134 displaceable relative to the lower frame section along a line of travel angularly displaced approximately 12° from the vertical. The upper end of the lower frame section 133 is supported on and displaceable along a transversely disposed guide rail (not shown) and the lower end of the lower frame section is displaceable along a transversely disposed guide rail 133a. Steering column assembly 25 is mounted on upper frame section 134 so that the axis of steering shaft 37 is substantially parallel to the line of travel of upper frame section 134 when displaced relative to lower frame section 133. As previously mentioned, steering shaft 37 has a slot and key type of connection with a gear of gear box 39 to permit the shaft along with column 36 to be displaced with the upper frame section. In addition to the wheel column assembly, foot pedals and other vehicle control devices are mounted on the upper frame section of the steering axle assembly.

Seat assembly 131 includes a pair of vertically disposed, transversely spaced channel-shaped support members 135 and 136 supported on the body of the vehicle. Supported on vertically displaceable members in such channel members is a support base 137 on which there

is supported a pair of longitudinally spaced, transversely disposed rails 138 and 139. Mounted on such rails and slightly displaceable transversely is an operator's seat 140.

Steering axle assembly 130 is manually slidable transversely to provide either left hand or right hand drive of the vehicle. Suitable motors and drives are provided for displacing upper frame section 134 relative to lower frame section 133, and associated seat 140 relative to support member 135 and 136, so that the operator will be permitted to operate the vehicle while entirely enclosed within the vehicle or at an upper position with the upper body of the operator extending through an opening in the roof portion of the vehicle.

In order to prevent scrubbing of the wheels and difficult steering, all of the steerable wheels are provided with steering geometry to provide a full Ackerman effect. With such geometry, upon turning left or right, the extended axes of all of the steerable wheels will intersect at a common point on a line perpendicular to the longitudinal centerline of the vehicle at a center point thereof, and all of such wheels upon turning will travel along concentric tracks. Such common intersection of the axes of all steerable wheels can be achieved by a simple modification of the knuckle bracket arrangements of the forward most and rearward most steering assemblies, and an equally simple modification of the linkages of the slaved steering assemblies, as the wheel base of the vehicle varies.

In the master steering assemblies which would include the first and second assemblies of the 4x4 wheel configuration, the first and third assemblies of the 6x6 wheel configuration, the first and fourth assemblies of the 8x8 configuration and the first and fifth assemblies of the 10x10 configuration, the geometry for providing a full Ackerman effect is achieved by arranging for the axis of the pivotal connection of each tie rod to its respective knuckle bracket being disposed on a linear line passing through the steering axis of an associated wheel and the center point of the vehicle. Generally, this may be accomplished by displacing the axis of each of the knuckle bracket/tie rod pivotal connection transversely, and varying the distance between the axes of the pivotal connections between the tie rods and the interconnecting slidable plate a corresponding amount. The amount of displacement is a function of the wheel base of the vehicle or the distance of the wheels from the transverse centerline of the vehicle. The greater the wheel base of the vehicle, the lesser the displacement required. In the several embodiments described herein, the 4x4 configuration is likely to require the greatest displacement, and the 10x10 configuration is likely to require the least displacement, approaching a zero displacement.

Mechanically, a sufficient displacement of the knuckle bracket/tie rod pivotal axis to provide an Ackerman steering geometry may be achieved in the master steering assemblies of the several embodiments described herein by providing either differently configured knuckle brackets or a single knuckle bracket configuration and a number of spacers of different thicknesses, each of which would be positioned between the common knuckle bracket and its associated knuckle plate. Since a commonality of components of the various embodiments of the vehicles is desirable, it is preferred that the displacement adjustment required to provide an Ackerman steering geometry for each of the master steering assemblies, be accomplished by the use of a single knuckle bracket configuration and spacers of different thicknesses.

In each of the slaved steering assemblies which would include the second and third assemblies of the 8x8 wheel configuration and the second and fourth assemblies of the 10x10 wheel configuration, the Ackerman steering geometry is achieved by suitably configuring crank arms 91 and 92. In the assembly shown in Figure 10, such adjustment is made by radially displacing the axis of connecting pin 93 relative to the axis of support pin 84, angularly displacing the axis of connecting pin 93 relative to a linear line passing through the axes of support pin 84 and connecting pin 100 and combinations of such displacements. A similar adjustment is made relative to crank arm 92. Essentially, for different wheel configurations, this would involve the selection of appropriate configurations of crank arms 91 and 92.

Figures 16a through 18b illustrate diagrammatically the different wheel configurations each without a geometry providing a full Ackerman effect and with a geometry providing such effect, incorporating the modifications of the master and slaved steering assemblies as described. Figure 16a illustrates a diagram of a 4x4 wheel configuration in which the axis of each pivotal connection of the knuckle bracket and its associated tie rod of each wheel fails to fall within a linear line intersecting the steering axis of such wheel and the center point of the vehicle. Figure 16b illustrates the wheel configuration shown in Figure 16a, in a turning mode. It will be noted that the extended axes of the inner wheels intersect at a common point spaced from the intersection of the extended axes of the outer wheels. Figures 16c and 16d illustrate the same 4x4 wheel configuration having the axis of each pivotal connection of a knuckle bracket and tie rod of each wheel intersecting a linear line from the steering axis of such wheel to the center point of the vehicle. Figure 16d illustrates the 4x4 wheel configuration shown in Figure 16c, in a turning mode, in which it will be noted that the axes of both the inner and outer wheels intersect

at a common point on a line perpendicular to the centerline of the vehicle at a center point of the vehicle.

Figures 17a and 17b illustrate an 8x8 wheel configuration without a geometry providing a full Ackerman effect. As shown in Figure 17b, the axes of the inboard and outboard wheels intersect at spaced points. Figures 17c and 17d illustrate the same configuration shown in Figures 17a and 17b but with each wheel having a geometry providing a full Ackerman effect, providing for all of the axes of the inner and outer wheels intersecting at a common turning axis.

Figures 18a and 18b illustrate diagrammatically a 10x10 wheel configuration in straight ahead and turning modes. Because of the greater wheel base of such configuration, geometry providing a full Ackerman effect is achieved without any or near zero spacing adjustment of the master and slaved wheel assemblies.

In view of the foregoing, it will be appreciated that there is provided a novel steering system which is adapted to utilize different combinations of a master steerable assembly, a slaved steerable assembly and a nonsteerable assembly, having a large commonality of components, to accommodate vehicles having 4x4, 6x6, 8x8 and 10x10 wheel configurations, which may easily be converted to provide either right hand or left hand drive and which further is highly responsive to manual steering motions.

From the foregoing detailed description, it will be evident that there are a number of changes, adaptations and modifications of the present invention that come within the province of those having ordinary skill in the art to which the present invention pertains. However, it is intended that all such variations not departing from the spirit of the invention be considered as within the scope thereof as limited solely by the following claims.